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INVESTIGATORY ANALYSIS OF ENERGY REQUIREMENT OF A MULTI-TENANT MOBILE COMMUNICATION BASE STATION

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Abstract: Energy consumption in mobile communication base stations (BTS) significantly impacts operational costs and the environmental footprint of mobile networks. This study examines the energy requirements of a multi-tenant BTS, focusing on power consumption patterns, key energy-intensive components, and optimization strategies. Empirical measurements under varying load conditions revealed that power consumption is network load-dependent and time-dependent, with peak demand occurring between 9:30 AM – 2:30 PM and 7:30 PM – 11:30 PM. The multi-tenant BTS required approximately 7.67 kW, compared to 2.5 kW for a single-tenant BTS. Additionally, the annual cost of diesel for generator power was estimated at ₦17,712,000, emphasizing the financial strain of conventional energy sources. A standalone solar power system is recommended as a sustainable alternative, designed to meet the identified power demands. A multi-tenant BTS model is also presented as a test-bed for designing and simulating a suitable solar power system. Power amplifiers and cooling systems were identified as the most energy-intensive components. Implementing dynamic load management and renewable energy solutions can significantly reduce energy demand, enhance efficiency, and lower operational costs. This study offers practical recommendations for optimizing energy use in multi-tenant BTS operations, supporting cost-effective, reliable, and sustainable mobile network infrastructure.
Keyword: Energy Efficiency, Mobile Network Sustainability, Multi-tenant Base Station, Power Consumption, Solar Power System.

1.0 Introduction

Mobile communication base stations (BTS) play a critical role in the operation of wireless communication networks, providing connectivity for voice, data, and multimedia services (Abonyi & Rigelsford, 2018) . As the demand for mobile services continues to grow, driven by the proliferation of smartphones, IoT devices, and high-speed internet, the energy consumption of base stations has become a significant concern. Studies indicate that BTS operations account for approximately 60-80% of the total energy consumption of mobile networks, making them a primary contributor to operational costs and environmental impacts (Hasan et al., 2021; Zhang et al., 2022).

The introduction of multi-tenant base stations, where multiple mobile network operators (MNOs) share infrastructure, has been widely adopted as a cost-effective solution to reduce capital expenditures (CapEx) and optimize resource utilization. However, this approach introduces new challenges, particularly in energy

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management, as varying traffic loads and operational requirements from different tenants create complex energy demand patterns (Li et al., 2020). For instance, peak energy consumption often coincides with high traffic loads, leading to inefficiencies and increased operational costs (Buzzi et al., 2021).

Recent research has highlighted the need for innovative strategies to address the energy challenges of BTS operations. Renewable energy integration, such as solar and wind power, has emerged as a promising solution, with studies showing potential energy offsets of up to 40% in regions with high solar irradiance (Ahmed et al., 2022). Additionally, energy-efficient hardware, such as advanced power amplifiers and cooling systems, has been shown to reduce energy consumption by up to 30% (Kumar et al., 2021).

Dynamic power management techniques, including tenant-based load balancing and real-time energy monitoring, have also gained attention for their ability to optimize energy use in multi-tenant configurations (Zhao et al., 2023). These techniques leverage traffic data and predictive algorithms to allocate energy resources more efficiently, reducing wastage and improving overall system performance.

Despite these advancements, there is limited research specifically focused on the energy requirements and optimization strategies for multi-tenant BTS in developing regions, where unreliable energy infrastructure and high operational costs pose additional challenges. This study aims to bridge this gap by investigating the energy consumption patterns of multi-tenant BTS, identifying key energy-demanding components, and evaluating the potential of renewable energy integration and dynamic power allocation strategies.

By providing a comprehensive analysis of energy requirements and optimization opportunities, this research contributes to the broader goal of achieving sustainable and cost-effective mobile network operations. It also aligns with global efforts to reduce carbon footprints and promote green telecommunications, as emphasized in the United Nations Sustainable Development Goals (UN SDGs) (United Nations, 2023).

2.0 Methodology

A typical mobile network Base Station (BS) was investigated with the aim of determining the load requirement, the power consumption and subsequently the maximum power required to power such base station. This will help in determining the capacity of the renewable energy system required to power a multi-tenant mobile communication base station.

An outdoor macro-cell BS with site number T4733 situated at Ogoja road, Abakiliki and managed by IPT Power Tech Limited was investigated. The BS shown in Figure 1 is a three tenant BS housing Airtel Nigeria Limited, MTN Nigeria Limited and 9Mobile Nigeria Limited. The Airtel network provider is operating a $2G, 3G\ and\ 4G$ networks , MTN is operating $2G\ and\ 3G$ while 9Mobile is operating only $2G$ network.

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Figure 1. Outdoor Macrocell BTS T4733 Site

The site comprises two main power sources, a generating set and a battery bank. The generator rating is 21KVA which is 17KW connected in series and then parallel. The battery bank is made up of 36 batteries each with a rating of 7.5V/160Ah. The switching between these two sources is controlled by the automatic transfer switch system referred to as Power solution. The 220VAC from the generator is converted to 54VDC by the rectifier. The output of the rectifier charges the battery banks as well as feeds the distribution board which supplies power to all base station equipment. The antennas were mounted on a 36m high mast and connected to the radio units at the base station via feeder cables.

The power consumption of the site was obtained by actual real-time measurement of the voltage and DC flowing through the electricity supply cable of the base station equipment using Clamp-ON meter and Probe Wires. Measurement carried out at the energy consumption box during the period of measurement (1300hours) shows that the available power for the cell site is 7666W i.e. ≈ 7.666kW.

To obtain sufficient data for proper analysis and reasonable conclusion, recorded data was obtained from the BTS performance and monitoring software tool for a period of one month at an interval of five minutes from 20^{th} January, 2024 to 18^{th} February, 2024. The collected data was used to carry out the following analysis;

3.0 RESULTS AND ANALYSIS

3.1 Effect of Load on Power Consumption of the BS

To investigate the effect of load on power consumption of a typical BS, load power data from 20/01/24 to 18/02/24 for a 5 minutes interval was plotted as shown in Figure 2. This result reveals a drop in power consumption between 12 midnight and 7am and then a gradual rise with peaks between 9.30am and 2.30am. There is another gentle rise in power consumption between 2.30pm and 12midnight with peaks between 7.30pm

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and 11.30pm. The graph follow the same pattern for each day for all 30 days under investigation. It can therefore be deduced that power consumption in a mobile network base station is subject to the network load which is dependent on the time of the day. From the graph, it can be concluded that busy hours in a mobile base station is between 9.30am and 2.30pm which can be described as office hours and also between 7.30pm and 11.30pm which can be described as leisure hours.

Since load has affects the power consumption of a BS, a renewable energy system can be designed for either;

- Busy hour with a power requirement of about 6081W- 6638W
- Less Busy hours with a power requirement of about 4207W - 5531W
- Both busy and less busy hours with a power requirement of at least 7666W as physically measured.

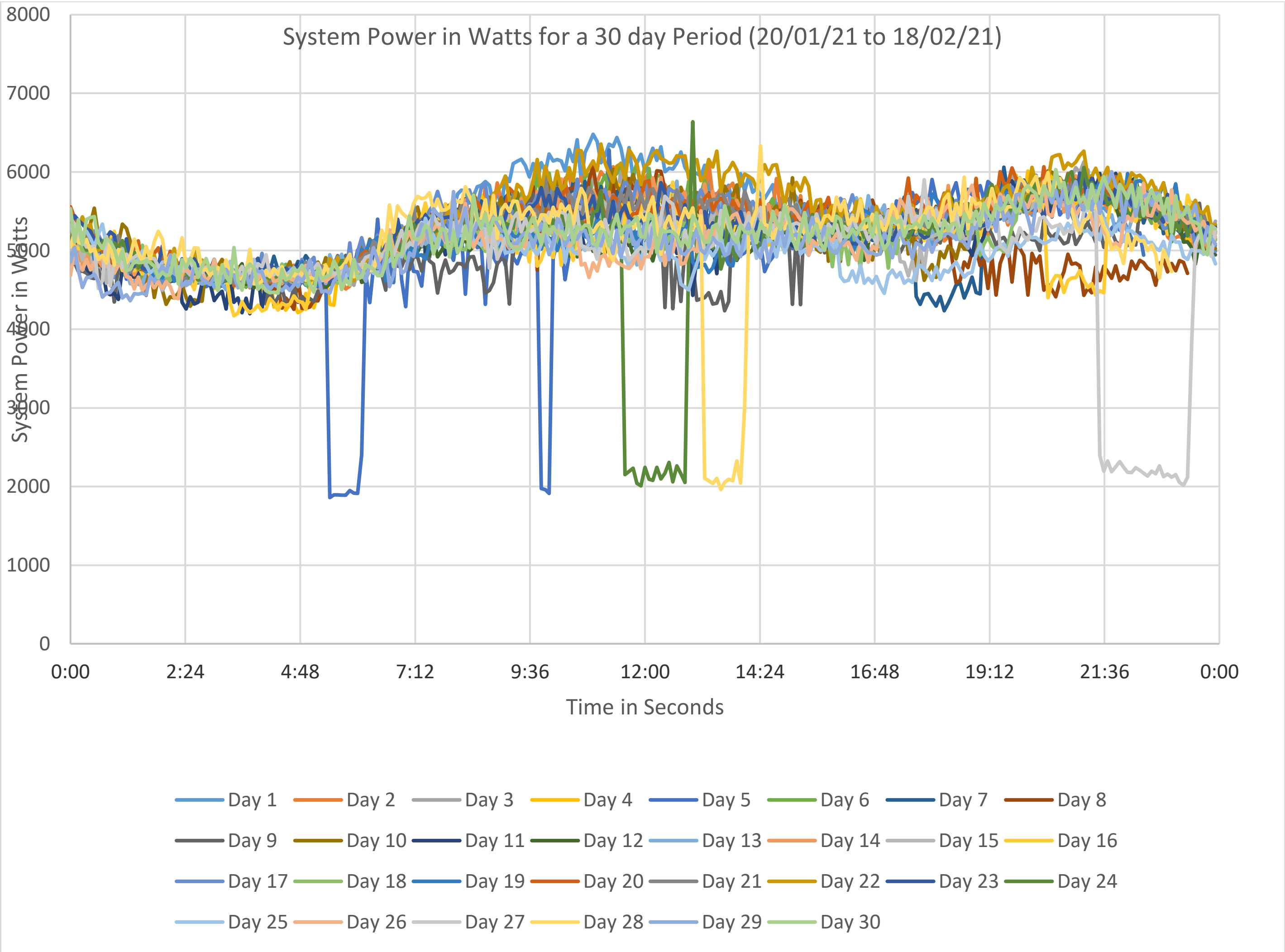

Figure 2. Relationship between system power and time

3.1.2 Relationship Between weekday and Power Consumption of a BS

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To investigate if the power consumption of a mobile network is dependent on the weekday or weekends. The average system power per day from 20/01/24 to 18/02/24 (30 days) at an interval of 5 minutes was calculated and plotted as shown in Figure 3. This result is analyzed in Table 1.

Table 1: Analysis of relationship between System Power and week day

Weeks	Minimum Power	Maximum Power
1	Sunday	Wednesday
2	Thursday	Friday
3	Thursday	Friday
4	Monday	Wednesday

From Table 1, Wednesdays and Fridays are suspected high traffic days but further investigation with more data is required before statistically significant conclusion can be drawn.

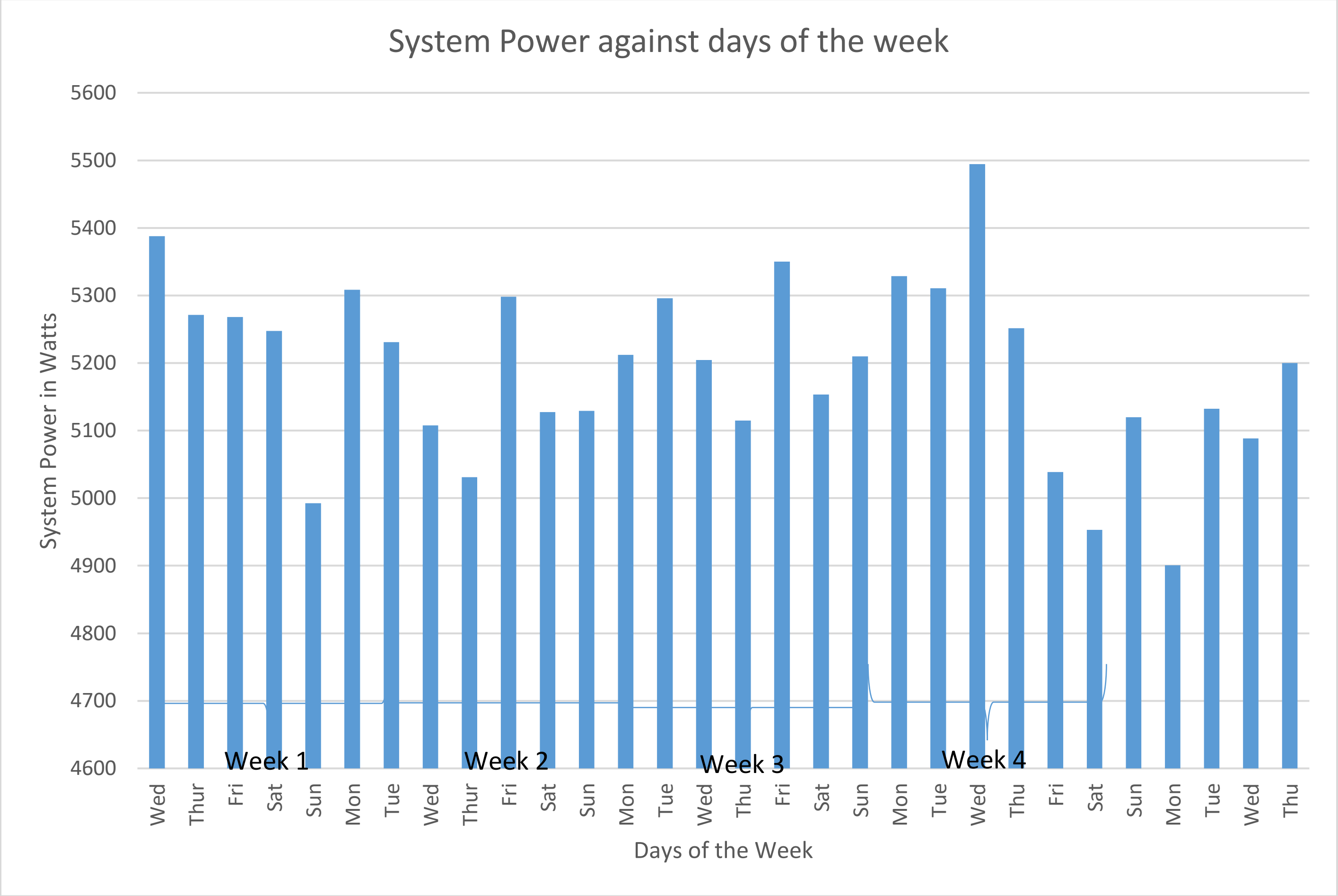

Figure 3. Relationship between system power and days of the week

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3.3 Effect of Priority of a Network on the Base Station Power Consumption

Information gathered revealed that in case of insufficient power at the base station visited, one tenant of the base station is normally given priority over others based on their commitment to funding the base station. From Figure 2, the sudden power drop between 5.25am-6am and 9.55am-10am on day 5 and also between 11.35am-12.50pm on day 24 and also 1.20-2.00pm on day 28 and 9.45pm-11.20pm on day 27 are most likely going to be due to one network being given priority over others. This means that at this time only one network provider's facility is powered. The minimum and maximum system power at these times are 1858W and 2323W respectively. It can therefore be deduced that a renewable energy system can be designed for a single tenant base station with a system power output target of 2.5KW.

3.4 Comparison of System Measured Power and Actual System Power

Comparing the actual measured system power and the system power data obtained from the BS performance and monitoring software tool, it can be observed that the actual measured data at 1300hours on the day of visit was 7666W but the system measured power at the same time on a different day was 6638W. This is actually, the maximum power for the whole month and it is 1028W less than the actual measured data. This is an indication that the system is not very 100% accurate.

This means that to design a renewable energy system for a multi-tenant base station, a considerable tolerance needs to be observed in determining the power rating of the system to ensure loads are comfortably powered without over-stressing the power system.

4.0 Cost Implication of Running a Multi-tenant Base Station

The generator on the visited site has a rating of 21KVA (17KW). Information obtained revealed that the generator average working hour is 8hours/day. The average diesel consumption per hour is 0.3liters/KWhour.

The relationship between the output energy and consumption of diesel engine is given by Equation 1.

$Energy\ in\ Output: E = P \times h \times d\ (KWh)$ (1)

$Consumption\ of\ fuel: C = E \times CKwh(litre)$ (2)

Where;

E - active energy in the output of the diesel engine in KWh

P - active electric power in the output of the diesel engine in KW

h - number of hours per day the gen set runs

d – number of days the power generator runs

$CKwh$ - Consumption of fuel per KWh (usual value is between 0.3 and 0.6liter/KWh)

C – Consumption of fuel in litre

The energy output of the BS per day is deduced using Equation 1 as follows;

$$Energy\ in\ Output: E = 17 \times 8 \times 1\ (KWh)$$
$$Energy\ in\ Output: E = 136\ (KWh)$$

The fuel consumption of the On-site generator for 8hours deduced using Equation 2 is as follows;

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$$Consumption\ of\ fuel: C = 136 \times 0.3Kwh(litre)$$
$$Consumption\ of\ fuel: C = 41(litre)$$

A litre of diesel around the study area at the time of study was ₦1,200/litre. This means that an eight hourly diesel consumption of the BS for 41litres/8hour diesel consumption was ₦49,200/day and ₦1,476,000/month assuming an average of 30 days per month. This is about ₦17,712,000/year. This is quite expensive but with a renewable energy source like solar energy implementation, this cost will be saved over the years.

5.0 Power Model for a Multi-tenant Base Station

The model of the investigated BS power system was developed as shown in Figure 4. It shows the power architecture and the basic components of the BTS.

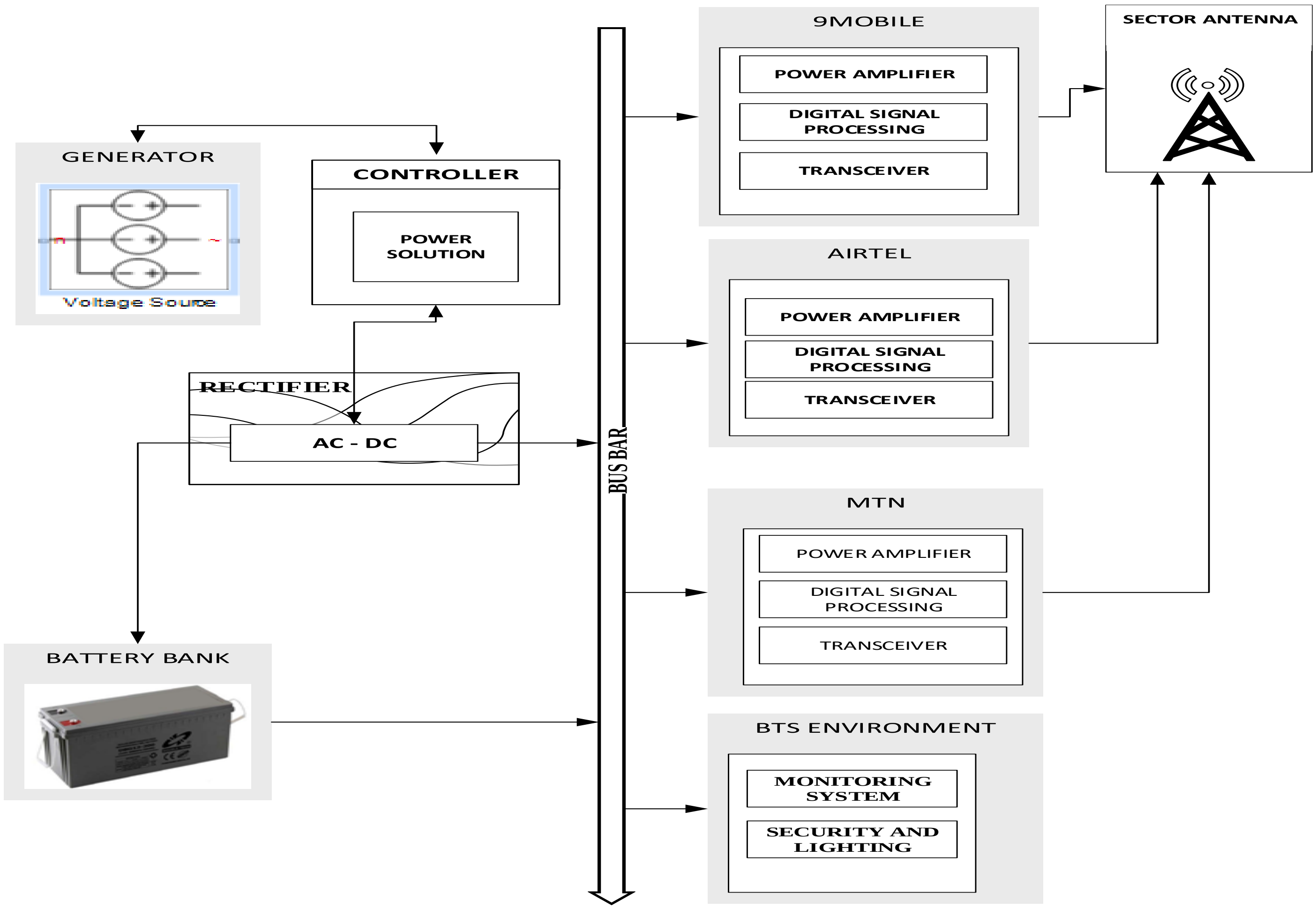

Figure 4. Power Architecture and Components of the BTS

The Base Station Power Solution shown in Figure 4 monitors the process of output power of the generator, charging of the batteries and required power to the base station, using the following scenarios:

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Scenario 1: The generator charges the batteries. The batteries fully charged at 54V supply the base station components till they dissipate to a maximum Depth of Discharge (DoD) of 48V.

Scenario 2: The generator at battery maximum DoD of 48V switches on, supplying the base station components and recharging the batteries as well.

The key components of the BTS are presented in Table 2. The power consumption of each of the components is used to determine the total power consumption of the BTS.

Table 2: Key Components of the Base Station

Key Components (Parameters)	Parameter Power Denotation
Baseband Unit - Digital Processing Unit	P_{DSP}
Transceiver	P_{TXR}
Amplifier	P_{AMP}
Rectifier	P_{RECT}
Microwave Link	P_{MICRO}
Environmental Monitoring System	P_{EMS}
Security and Lightings	P_{SL}

The essence of developing the power model of the base station is to aid in determining the power consumption of the cell site per day (CPD). It will also help in determining the power output of the base station through simulation. The CPD will be used in calculating the cost of running the site at any point in time.

Power P consumed by each component of the base station is given by:

$$P = IV \quad (3)$$

From Equation (1), the measured current varies with the traffic load for some components thus, the power consumption of a cellular base station can be categorized into two; load dependent P_{Load} and load independent $P_{Non-Load}$. Therefore, the total power consumed by the base station is given by:

$$P_{BS} = P_{Load} + P_{Non-Load} \quad (4)$$

Where,

$$P_{Load} = P_{TXR} + P_{AMP} \quad (5)$$

While

$$P_{Non-Load} = P_{RECT} + P_{DSP} + P_{MICRO} + \sum_{n=1}^{n} P_{SL} + \sum_{m=1}^{m} P_{EMS} \quad (6)$$

Where m and n are the number of environmental monitoring systems (EMS) and security and lighting (SL) respectively. The characterized three tenant base station is a tri-sector macro-cell with 120° coverage antennas mounted on a mast of … height. The power consumption of the base station components will be multiplied by the number of sectors P_{Sector}. The antenna is considered to be part of the radio transceiver unit (TXR). The remote radio unit (RRU) comprises the transceiver and the amplifier thus, the power consumed by RRU can be calculated as:

$$P_{RRU} = P_{LOAD} \quad (5)$$

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For this base station, the number of sectors is 3. Apparently, the power consumption is determined using:

$$P_{RRU} = P_{Sector0} + P_{Sector1} + P_{Sector2} \quad (6)$$

Therefore,

$$P_{RRU} = \sum_{n=0}^{2} P_{Sector} \quad (7)$$

The total power P_{BS} consumed in the base station is deduced as follows:

$$P_{BS} = \sum_{n=0}^{2} P_{Sector} + P_{RECT} + P_{DSP} + P_{MICRO} + \sum_{n=1}^{n} P_{SL} + \sum_{m=1}^{m} P_{EMS} \quad (8)$$

Measurement carried out at the energy consumption box during the period of measurement in line with Equation (8) shows that the available power for the cell site is 7666W i.e. ≈ 7.666kW. To determine the power consumption of the individual service providers, measurement was carried out in accordance with Equation (6) and the values achieved were tabulated in Table 3.

Table 3: Daily Power Consumption of the three Network Providers

Network Provider	**Network Type**	**Voltage *V***	**Current *I(Amp)***	**Power *P(w)***
MTN	3G	48.3	36	1,738.8
MTN	2G	48.3	22	1,062.6
Airtel	2G, 3G, 4G	48.3	65	3,139.5
9Mobile	2G	48.3	33	1,593.9
Total				**7,534.8**

From Equation (8), power consumed for various categories of equipment can be deduced using communication and non-communication equipment. Power consumption using communication equipment is given by: $\sum_{n=0}^{2} P_{Sector} + P_{RECT} + P_{DSP} + P_{MICRO}$

While non-communication equipment is given by: $\sum_{n=1}^{n} P_{SL} + \sum_{m=1}^{m} P_{EMS}$

From Table 3, the total power consumed by the communication equipment of the base station is;

$$\sum_{n=0}^{2} P_{Sector} + P_{RECT} + P_{DSP} + P_{MICRO} = 7{,}534.8\text{W}$$

Measurement carried out on the base station environmental monitoring, security and lighting yields:

$$\sum_{n=1}^{3} P_{SL} + \sum_{m=1}^{1} P_{EMS} = 90\text{W}$$

Power consumption per day (CPD) can be deduced as:

7,534.8 + 90 = 7624.8w ≈ 7.625kw

Power losses P_{Loss} can be determined through the difference between the available power and consumed power;

7.666kw – 7.625kw = 0.041kw

5.0 Simulink Model of the Multi-tenant BS

Using the above scenarios, the power consumption model of the investigated base station was implemented in the Simulink Simscape environment for simulation as shown in Figure 5.

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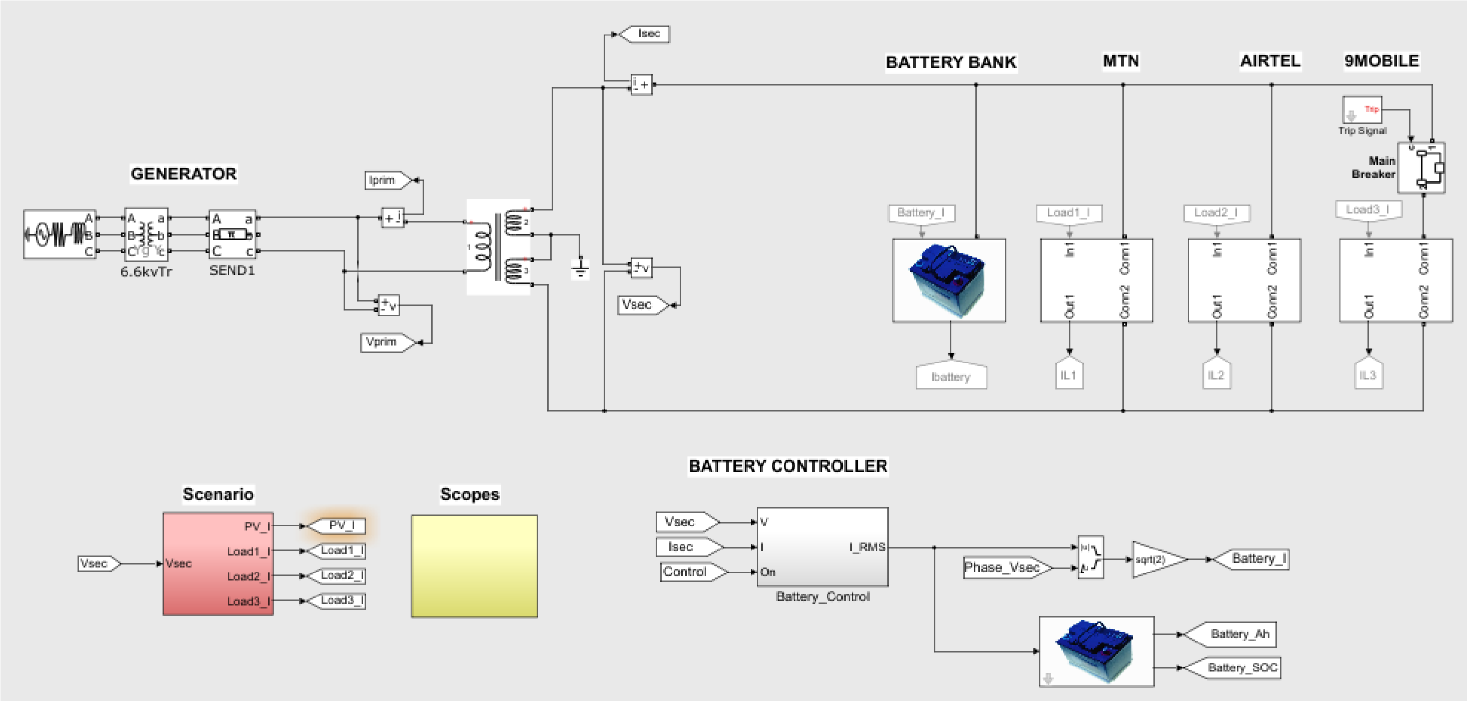

Figure 5: Simscape Model of the Base Station

The Simscape power model of the base station is designed such that the three-phase alternating current from the generator source is connected to a distribution transformer. The distribution transformer steps down and changes the voltage to single-phase AC (200 V). The frequency of AC cycles is set to 50 Hz. The battery bank is a DC power source. Both the generator and the battery bank are connected to the bus bar through the BTS Power solution. As a typical load change in a BTS, the amount of electric power load reaches peak consumption at time between 9.30AM and 2.30PM (6,081W to 6,638W) and between 7.30PM and 11.30PM (6,053W to 6,263W).

The simulation is carried out based on the following:

- From 6AM to 12PM and from 6PM to 12AM, battery control is performed by battery controller. The battery control performs tracking control of the current so that active power which flows into system power from the secondary side of the pole transformer is set to 0. Then, the active power of the secondary side of the distribution transformer is always around zero. The battery bank supplies insufficient current when the power of the generator is cut off.
- From 12PM to 6PM, battery control is not performed. SOC (State of Charge) of the battery bank is fixed to a constant and does not change since charge or discharge of the storage battery is not performed by the battery controller. At 8AM or in a system collapse situation, the electricity load of the non-priority tenant is set to OFF for a stipulated time by the breaker.

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5.1 Simulation Result

The result obtained from the simulation model of the BS is shown in Figure 6

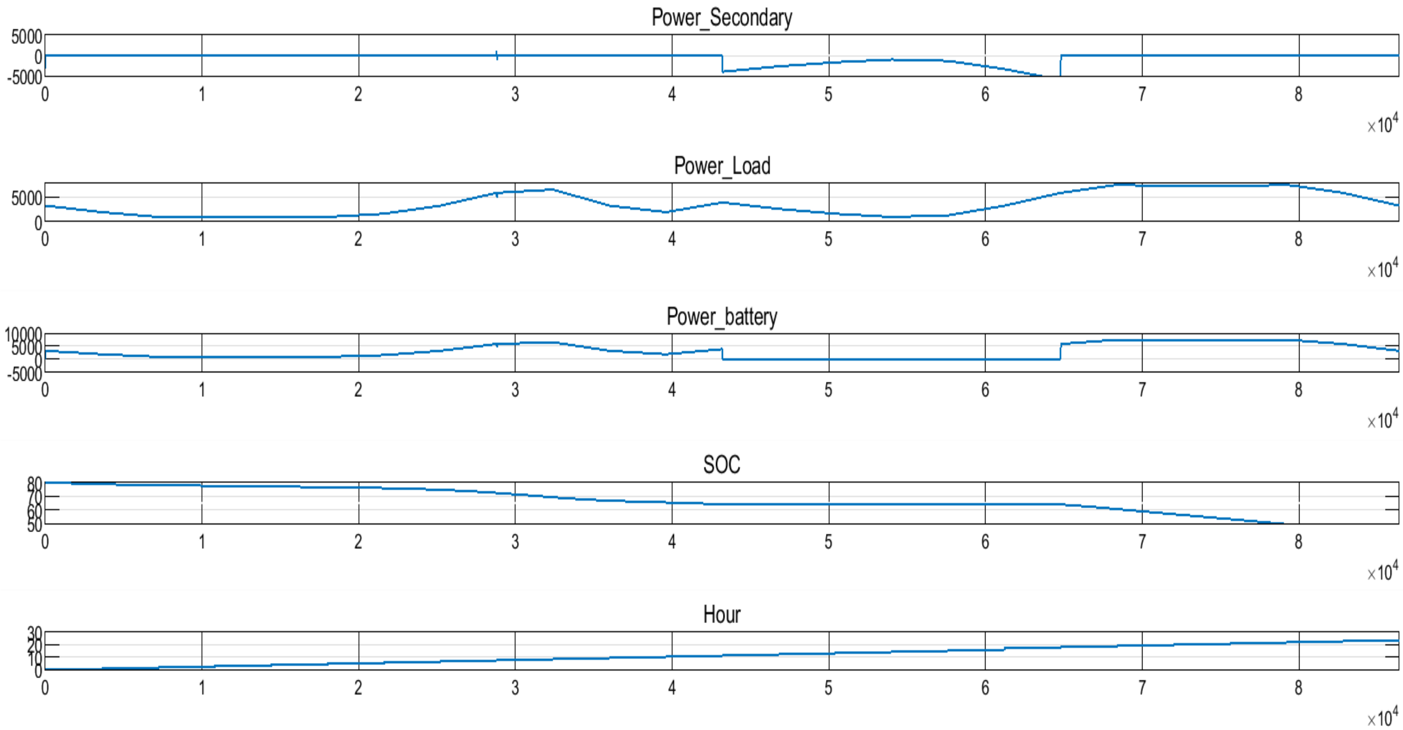

Figure 5: Simulation Graph Model of the Base Station

In Figure 5, from the range scale ($0 - 4.4 \times 10^4$), the zero flat lines of the Generator (power secondary) showed that no energy is supplied by the generator. Hence, the power solution monitors the state of charge (SOC) of the battery which was fully charged and switches the load to the batteries. The batteries only feed the load and it can be seen that the movement of the power variation of the load is consistent with the battery. As the depth of discharge of the battery reduces to a certain level, the power solution starts the generator (from the range scale of $4.4 - 6.5 \times 10^4$) and switches the load to the generator. At the same time, the generator becomes a battery charger. The movement of the power variation of the generator is inconsistent with the load since the generator is feeding the load and charging the batteries at the same time. It can be seen that the "Power_battery" is at zero levels and the graph of SOC is constant which means that the battery is not discharging. The range scale of $6.5- 9\,x\,10^4$ shows that the power solution has switched back to the batteries, the load is being driven with the power from the batteries and the depth of discharge of the battery is reducing. In conclusion, the simulation result conforms to the existing power system flow of the characterized base station making it a suitable test bed for the design and simulation of a renewable energy system for Energy Optimization in a Mobile Communication Base Station.

6.0 Conclusion

This study highlights the critical role of energy management in multi-tenant mobile communication base stations, where diverse traffic loads and shared infrastructure introduce unique challenges. The findings reveal that power amplifiers and cooling systems account for the majority of energy consumption, making them prime targets for optimization. Renewable energy integration, dynamic power allocation, and tenant-based load balancing are identified as effective strategies for reducing energy demand and operational costs.

Moreover, the study underscores the importance of adopting energy-efficient technologies and implementing proactive maintenance to enhance system reliability and sustainability. By addressing these factors, mobile network operators can achieve significant cost savings while contributing to environmental sustainability. Future research should focus on developing real-time energy monitoring systems and advanced optimization algorithms to further enhance the energy efficiency of multi-tenant base stations.

This work provides a foundation for sustainable practices in mobile network operations, aligning with global efforts to reduce carbon footprints and promote green telecommunications.

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The authors sincerely appreciate the Nigerian Communications Commission (NCC) for sponsoring this research through Enugu State University of Science and Technology (ESUT). Their financial support and commitment to advancing telecommunications research have been instrumental in the successful execution of this study. We also acknowledge ESUT for providing the necessary resources and an enabling environment for this research.

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